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Changes in the Composition of Raw Tea Leaves from the Korean Yabukida Plant during High-Temperature Processing to Pan-Fried Kamairi-Cha Green Tea

MENDEL FRIEDMAN, CAROL E. LEVIN, SUK-HYUN CHOI, SEUNG-UN LEE, AND NOBUYUKI KOZUKUE

ABSTRACT: To develop a better understanding of compositional changes occurring during the production of commercial teas, we determined by high-performance liquid chromatography (HPLC) changes in ingredient levels during each of several manufacturing steps used to produce Kamairi-cha, a premium green tea. Kamairi-cha uses pan-frying instead of the usual blanching technique to inactivate the enzymes responsible for producing traditional black tea. The resulting tea lacks the characteristic bitterness of green tea, producing a green tea that is described as sweet tasting. The processing steps used to produce this pan-fried tea were as follows: 1st roasting, 1st rolling, 2nd roasting, 2nd rolling, 1st firing, and 2nd firing. The results show that during production at temperatures up to 300 °C, raw leaves lost (in percent) 97.3 water, 94 two chlorophylls, 14.3 seven catechins, and 2.75 caffeine. A separate analysis showed that the final product contained 21.67 mg/g dry wt of the biologically active amino acid theanine. The results of this 1st report on changes in individual catechins and other tea ingredients in tea leaves during pan-frying make it possible to select production conditions that maximize levels of beneficial tea ingredients. The possible significance of the results for the human diet is discussed.

Keywords: catechin, Kamairi-cha, pan-fried, tea, theanine

Introduction

Tea leaves produce organic compounds that may be involved in the defense of the plants against invading phytopathogens (Chiu 2006; Ho and others 2009). These secondary metabolites include polyphenolic catechins present in green teas, oxidation products of catechins formed during fermentation called theaflavins present in black teas, and the 3 methyl-xanthine alkaloids caffeine, theobromine, and theophylline that may be present in both tea categories. Tea leaves also contain the biologically active amino acid theanine (Figure 1). Catechins, theaflavins, and theanine are reported to have numerous beneficial effects when consumed as part of the human diet (Cui and others 2008; Miyagawa and others 2008; Owen and others 2008; Patel and others 2008; Bolling and others 2009).

In the course of previous studies designed to determine the composition of commercial tea leaves, we developed improved extraction and analysis methods that can be used to determine the content of all these ingredients (Friedman and others 2005, 2006b). In related studies, we found that catechin levels decrease during storage of commercial teas (Friedman and others 2009) and explored inhibitory activities of tea catechins, theaflavins, and the amino acid theanine against human cancer cells (Friedman and others 2007) and of tea flavonoids and teas against foodborne pathogenic bacteria (Friedman and others 2006a; Friedman 2007; Juneja and others 2007, 2009; Sirk and others 2008).

Most green teas produced from fresh tea leaves undergo steam treatment, which results in teas with a characteristic bitter taste. Because the rare Kamairi-cha green tea does not undergo the usual steam treatment but is exposed to a high-temperature treatment called pan-frying in hot iron pans, the tea has a sweet taste and pleasant flavor. Processing conditions can have a dramatic effect on flavonoid content. Black tea, which is made from the same plant but is processed differently, that is, fermented, has a distinctly different flavonoid profile than green tea. Most of the catechin content is converted into theaflavins during the fermentation process. While still antioxidative, theaflavins may have different effects on health (Cooper and others 2005). Green teas that have been pasteurized for use in bottled tea drinks have been shown to have a high rate of epimerization of catechins from the more abundant *cis* (*epi*) form (Chen and others 2001) to the *trans* form. Epimerized *trans*-catechins were found to have stronger superoxide scavenging abilities (Guo and others 1999) and may possibly be more hypocholesterolemic (Ikeda and others 2003) than their *cis* counterparts. It is apparent that tea processing can affect the quantity and quality of health-giving constituents. It is therefore of inherent interest to determine the fate of catechins and alkaloids during the multiple steps used in the preparation of the specialty variety tea, called green Kamairi-cha tea. This tea has a distinctively different taste than traditional green tea, although it is classified as a green tea because it has not been fermented.

Previous studies on Kamairi-cha green and other roasted teas reported that (1) the degree of rolling during the manufacturing process affects the catechin and amino acid content of Japanese Kamairi-cha tea (Kinugasa and others 1997); (2) the quality of

MS 20090056 Submitted 1/20/2009, Accepted 3/19/2009. *Authors Friedman and Levin are with Western Regional Research Center, Agricultural Research Service, U.S. Dept. of Agriculture, Albany, CA 94710, U.S.A. Author Choi is with Dept. of Food Service Industry, Seowon Univ., 361-742, Mochung-dong, Heungduk-gu, Cheongju-city, Chungbuk, Korea. Authors Lee and Kozukue are with Dept. of Food Service Industry, Uiduk Univ., 780-713, Gangdong, Gyeongju, Gyongbuk, Korea. Direct inquiries to author Friedman (E-mail: Mendel.Friedman@ars.usda.gov).*

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Japanese Kamairi-cha green tea is influenced by the distribution of heat in contact with tea leaves (Gejima and Nagata 2000); (3) pan-frying of Japanese Kamairi-cha tea leaves produced 51 distinct and potent odor-active compounds formed by heat-induced Maillard type reactions between amino acids and sugar degradation products (Kumazawa and Masuda 2002); (4) controlling the roasting temperature can be used to mitigate acrylamide formation in this tea (Mizukami and others 2008); (5) volatile extracts

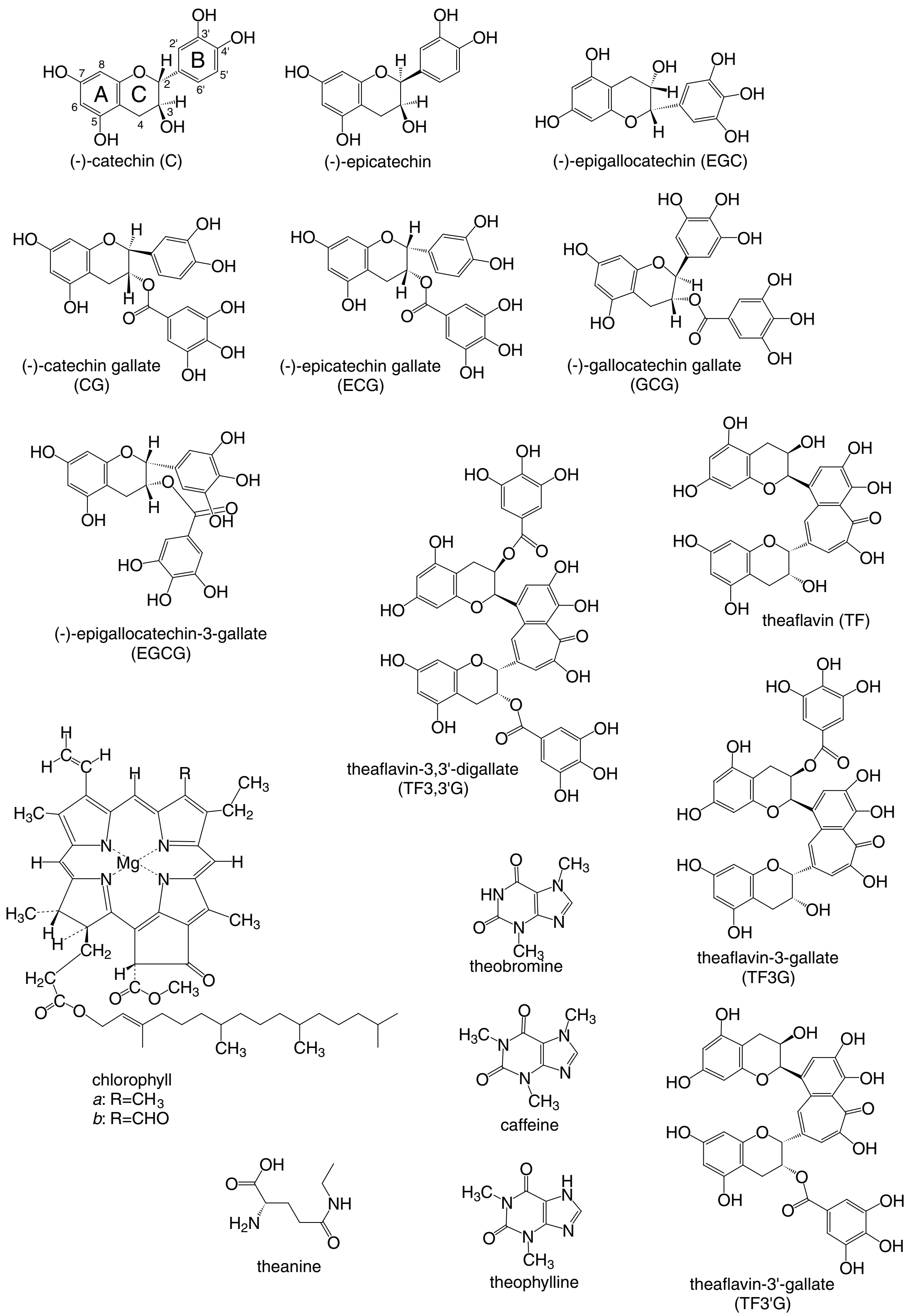

Figure 1 — Structures of 7 catechins, 4 theaflavins, alkaloids, 2 chlorophylls, and the amino acid theanine evaluated in this study.

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from roasted teas exhibited antioxidative properties (Yanagimoto and others 2003); (6) consumption of roasted tea was not associated with increasing incidence for stroke risk among Japanese men and women (Tanabe and others 2008); and (7) consumers prefer green teas prepared by "roasting" over those prepared by traditional methods (Lee and others 2008). Pan-fried teas are more expensive than teas produced by steaming of the leaves and are largely unavailable in Western countries (Wikipedia Encyclopedia 2008).

The main objectives of the present study were (1) to describe multistep processes we used to prepare Kamairi-cha green tea by pan-frying fresh tea leaves; (2) to determine changes in the levels of moisture, chlorophyll *a* and *b*, 7 catechins, and 3 alkaloids during each of several steps used in the manufacture of pan-fried green tea from fresh tea leaves to the final product; and (3) to determine the theanine content of the final product.

Materials and Methods

Materials

The following catechin and alkaloid standards with the indicated purities were obtained from Sigma/Aldrich (St. Louis, Mo., U.S.A.): (–)-epigallocatechin from green tea (EGC) (≥95%), (–)-catechin from green tea (C) (≥98%), (–)-epicatechin from green tea (EC) (≥98%), (–)-epigallocatechin gallate from green tea (EGCG) (≥95%), (–)-gallocatechin gallate from green tea (GCG) (≥98%), (–)-epicatechin gallate from green tea (ECG) (≥98%), (–)-catechin gallate from green tea (CG) (≥98%), caffeine (CAF) (≥98%), theobromine (TB) (≥99%), and theophylline (TP) (≥99%). Theaflavin, theaflavin-3-gallate, theaflavin-3'-gallate, and theaflavin-3, 3'-digalllate (all [≥90%] were obtained from Wako, Osaka, Japan). L-theanine was obtained from LKT Laboratories (St. Paul, Minn., U.S.A). high-performance liquid chromatography (HPLC) solvents were filtered through a 0.45-μM membrane (Millipore, Bedford, Mass., U.S.A.) and degassed in an ultrasonic bath before use.

Manufacture of Kamairi-cha (pan-fried tea)

Kamairi-cha tea was produced in a single batch. During various stages of the process, 50 g of sample were removed. Each of the resulting samples was analyzed in triplicate. The following steps were used to in the production of pan-fried Kamairi-cha green tea:

1. Tea leaves (3 kg) of the "Yabukida" plant (3-y-old plants) were harvested between 8 and 9 AM on April 23, 2007 at Bosung, Korea (Figure 2). Processing of selected leaves started at 5 PM of the same day.
2. Tea leaves (1.5 kg) were placed into a round iron pan (diameter, 1 m; bottom thickness, 3 cm; thickness of the rest of the pan, 1 cm, shown in Figure 2B). The following conditions were then used to process the leaves:

   a. Pan-heating: the pan was heated up to 250 to 300 °C by strong flue gases.
   b. 1st roasting: the tea leaves were mixed (hand-rolled) for 5 min.
   c. Cooling: the tea leaves were cooled by a fan immediately after roasting.
   d. 1st rolling: the leaves were machine-rolled for 5 min at 37 rotations/min.
   e. 1st selection: badly shaped tea leaves were removed by hand.
   f. 2nd roasting: the temperature of the pan was adjusted to 100 °C, and the tea leaves were then hand-mixed for 1 min.
   g. 2nd cooling: the leaves were then immediately cooled by a fan.
   h. 2nd rolling: the leaves were machine-rolled for 4 to 5 min at 37 rotations/min.
   i. 1st firing: the leaves were dried in a rolling drum at 40 to 50 °C for 4 h.
   j. 2nd firing: the leaves were dried in a rolling drum at 60 to 70 °C for 2 h. This final step generates the desirable rich flavor in the processed leaves.

Analysis of moisture content of tea leaves

The moisture content of the tea leaves following each processing step was determined by drying the samples in a vacuum oven at 70 °C in the presence of P_2O_5 for 12 h as described in the official AOAC method (AOAC 1965).

Figure 2—Harvesting of tea leaves. (A) The complete view of a tea garden at Bosung, Korea. (B) The iron pan used for manufacture of Kamairi-cha (Korean green tea). (C) Hand rolling. (D) Cooling of leaves by an electric fan immediately after the rolling process.

Analysis of chlorophyll *a* and *b* content of tea leaves

The procedure was adapted from the official AOAC method (AOAC 1965) and from a method we previously used with potato sprouts (Kozukue and others 2001). Briefly, the leaves (approximately 0.5 g) from each processing step and $MgCO_3$ (0.1 g) were macerated in a glass mortar with 80% acetone/water (15 mL). The sample was then centrifuged at 15000 × *g* for 10 min at 5 °C. The resulting pellet was extracted 3 times with of 80% acetone (10 mL) and centrifuged. The extracts were combined and adjusted with 80% acetone to a volume of 50 mL. This solution was used to analyze for 2 chlorophylls by visible spectrophotometry with the aid of a Shimadzu UV Mini 1240 Spectrophotometer (Shimadzu Corp., Kyoto, Japan). Chlorophyll *a* absorbs at 665 nm and chlorophyll *b* at 645.2 nm. Concentration of individual chlorophylls was calculated as described elsewhere (Kozukue and others 2001).

Extraction of tea leaves for catechin and alkaloid analysis

For extraction with distilled water, each tea sample (approximately 1.5 g) was placed into a 250 mL flask to which was added water (100 mL) that was previously brought to the boiling point. The sample was then stirred slowly with a magnetic stirrer for 5 min, cooled, and centrifuged at 18000 × *g* for 5 min at 5 °C. The supernatant was filtered through a 0.45 μM Millipore nylon filter before analysis.

HPLC analysis of catechins and alkaloids in tea leaves

The method was adapted from our previous studies (Friedman and others 2005, 2006b). HPLC was carried out on a Hitachi liquid chromatograph model 665-II equipped with an autosampler (model 655A-40, Hitachi, Ltd., Tokyo, Japan). The stainless steel column (250 × 4 mm i.d.) was packed with Inertsil ODS-3v (5 μM particle diameter) (GL Sciences, Tokyo, Japan). The column temperature was maintained constant with a Shimadzu column oven CTO-10vp (Shimadzu, Kyoto, Japan). The gradient system consisted of a mixture of acetonitrile and 20 mm KH_2PO_4. The flow rate was 1 mL/min at a column temperature of 30 °C. A Shimadzu photo diode array UV-VIS detector (model SPD-10Avp, Shimadzu) was set from 200 to 700 nm. The tea extract (10 μL) was injected directly into the column. Analyses, each in triplicate, were carried out with 3 separate extracts.

The initial composition of the mobile phase consisted of 7% acetonitrile (A) and 93% of 20 mm KH_2PO_4 (B) (v/v) was maintained for 6 min. Solvent A was then increased linearly to 10% in 20 min, 15% in 25 min, 20% in 30 min, and 25% in 45 to 70 min. Programming was then continued in the isocratic mode as follows: 40% B in 70.1 to 75 min and 7% A to 76.1 to 90.1 min.

Identification and quantification was accomplished by comparing integrated chromatographic peak areas from the test samples to peak areas of known amounts of standard compounds using the Hitachi Chromato-integrator model D-2500 (Hitachi Ltd., Tokyo, Japan). Each peak was identified by comparing the retention times and absorption spectra of unknowns to those of standards.

HPLC analysis of theanine in tea leaves

Extraction of theanine from tea leaves with boiled water and analysis as DNP-theanine by HPLC was performed as described previously (Friedman and others 2007).

Statistical analysis

Statistical analyses were performed on the analyzed catechin, alkaloid, and chlorophyll concentration changes found during the preceding processing steps using SigmaPlot 11 (Systat Software Inc., San Jose, Calif., U.S.A.). One-way analysis of variance (ANOVA) and Holm–Sidak multiple comparisons tests were used to determine statistical significance at the 5% level.

Results and Discussion

Moisture content

Table 1 shows that the 1st roasting causes a 6% loss of water, whereas the 2nd roasting caused no significant loss of moisture. The low decrease in water content in these high-heat processes is likely due to the short processing time. The 1st firing, designed to remove water and stabilize the tea against further fermentation, enzymatic activity, and oxidation, then causes an 88% loss of water. The 2nd firing removes an additional 7%. The overall loss was 98% of the original water content.

Chlorophyll *a* and *b* content

Because chlorophyll is reported to exhibit anticarcinogenic properties (Castro and others 2008; Simonich and others 2008), it was of interest to determine its fate during the processing steps used to prepare the green tea. Table 2 shows that the chlorophyll *a* and *b* content (in milligrams per gram dry wt) of the harvested tea leaves was 2.24 and 0.77, respectively. These values remained largely unchanged during the 2 roasting and 2 rolling steps. They then decreased sharply to 0.56 and 0.17 during the 1st roasting and to 0.13 and 0.04 during the 2nd firing, respectively. The final green

Table 1 – Moisture content of leaves during each of several stages of manufacturing of Kamairi-cha green tea.[a]

Processing conditions	Average ± SD
Raw tea leaf	75.54 ± 0.35
1st roasting[A]	71.10 ± 0.06[b,c]
1st rolling[B]	69.88 ± 0.65[b]
2nd roasting[C]	69.74 ± 0.44[b]
2nd rolling[D]	68.82 ± 0.65[b]
1st firing[E]	8.04 ± 0.24[b,c]
2nd firing[F]	2.35 ± 0.15[b,c]
Green tea[G]	2.04 ± 0.08[c]

[A]Pan roasted 250 to 300 °C, 5 min.
[B]Machine rolled, 5 min.
[C]Pan roasted 100 °C, 1 min.
[D]Machine rolled, 4 to 5 min.
[E]Drum-dried 40 to 50 °C, 4 hr.
[F]Drum-dried 60 to 70 °C, 2 hr.
[G]Cooled, finished product.
[a]Listed values are expressed as average (mg/g dry weight) ± SD; $n = 3$. Shading indicates significantly different than previous step.
[b]Significantly different than the previous processing step ($P < 0.001$).
[c]Significantly different than the starting material (raw leaves) ($P < 0.001$).

Table 2 – Changes in chlorophyll *a* and chlorophyll *b* content during the manufacture of Kamairi-cha green tea.[A]

Processing conditions[a]	Chlorophyll *a* (A)	Chlorophyll *b* (B)	(A) + (B)
Raw tea leaf	2.24 ± 0.40	0.77 ± 0.065	3.01
1st roasting	2.15 ± 0.15	0.73 ± 0.06	2.88
1st rolling	1.80 ± 0.24	0.62 ± 0.07	2.42
2nd roasting	2.15 ± 0.08	0.65 ± 0.01	2.81
2nd rolling	2.14 ± 0.11	0.73 ± 0.08	2.97
1st firing	0.56 ± 0.03[b,c]	0.17 ± 0.00[b,c]	0.73
2nd firing	0.13 ± 0.01[c]	0.04 ± 0.00[c]	0.17
Green tea	0.14 ± 0.01[c]	0.04 ± 0.00[c]	0.18

[A] Listed values are expressed as average (mg/g dry weight) ± SD; $n = 3$. Shading indicates significantly different than previous step.
[a]See Table 1.
[b]Significantly different than the previous processing step ($P < 0.001$).
[c]Significantly different than the starting material (raw leaves) ($P < 0.001$).

tea product contained only 0.14 chlorophyll *a* and 0.04 chlorophyll *b*, corresponding to a 16.7-fold decrease from the original value.

Flavonoid and alkaloid content

Figure 3 illustrates the separation by HPLC of green tea flavonoids (catechins) and alkaloids extracted from tea leaves when exposed to processing conditions used to prepare Kamairi-cha green tea. No gallocatechin or theaflavins were found in any of the extracts. Table 3 shows the tea content during processing of the 7 catechins and 3 alkaloids analyzed by HPLC. Kamairi-cha tea processing caused an overall loss of 14% of catechins, with no significant loss of total alkaloids.

Epigallocatechin sustained the largest loss (87%) of any of the analyzed tea components, decreasing (in milligrams per gram dry wt) from 9.53 in the raw leaves to 1.22 in the finished product. Most of that loss occurred at the 2nd rolling. Gallocatechin gallate and epicatechin also sustained significant losses (44% and 22%, respectively). Gallocatechin gallate decreased from 6.43 to 3.61 and epicatechin decreased from 8.91 to 6.93. While epicatechin experienced a gradual loss throughout the processing sequence, gallocatechin gallate had significant reductions at the 1st roasting and 1st firing stages, both high heat processes with longer processing times than the respective 2nd roasting and 2nd firing stages. It is also noteworthy that processing induced an overall 78% increase in catechin, from 5.55 to 9.89. Most of the catechin increase was seen at the 2nd firing stage. These results show that some catechins, especially epigallocatechin, are highly susceptible to heat-induced degradation, while others are much less so.

Table 3 also shows that the theobromine and caffeine content remained the same and that the theophylline content increased during the firing stage and final cooling of the leaves. There was no statistical difference in total alkaloid content between any of the processing steps. Caffeine concentrations, the most abundant of the 3 alkaloids, remained largely unchanged during all processing steps. We do not know why theophylline levels rose during the firing stage. Perhaps the alkaloid is more easily extracted from the dried leaf. However, the low values for theophylline listed in Table 3 do not allow definitive conclusions about changes that may have occurred.

Theanine content

Because teas also contain the biologically active amino acid theanine, we also determined its content in the final green tea

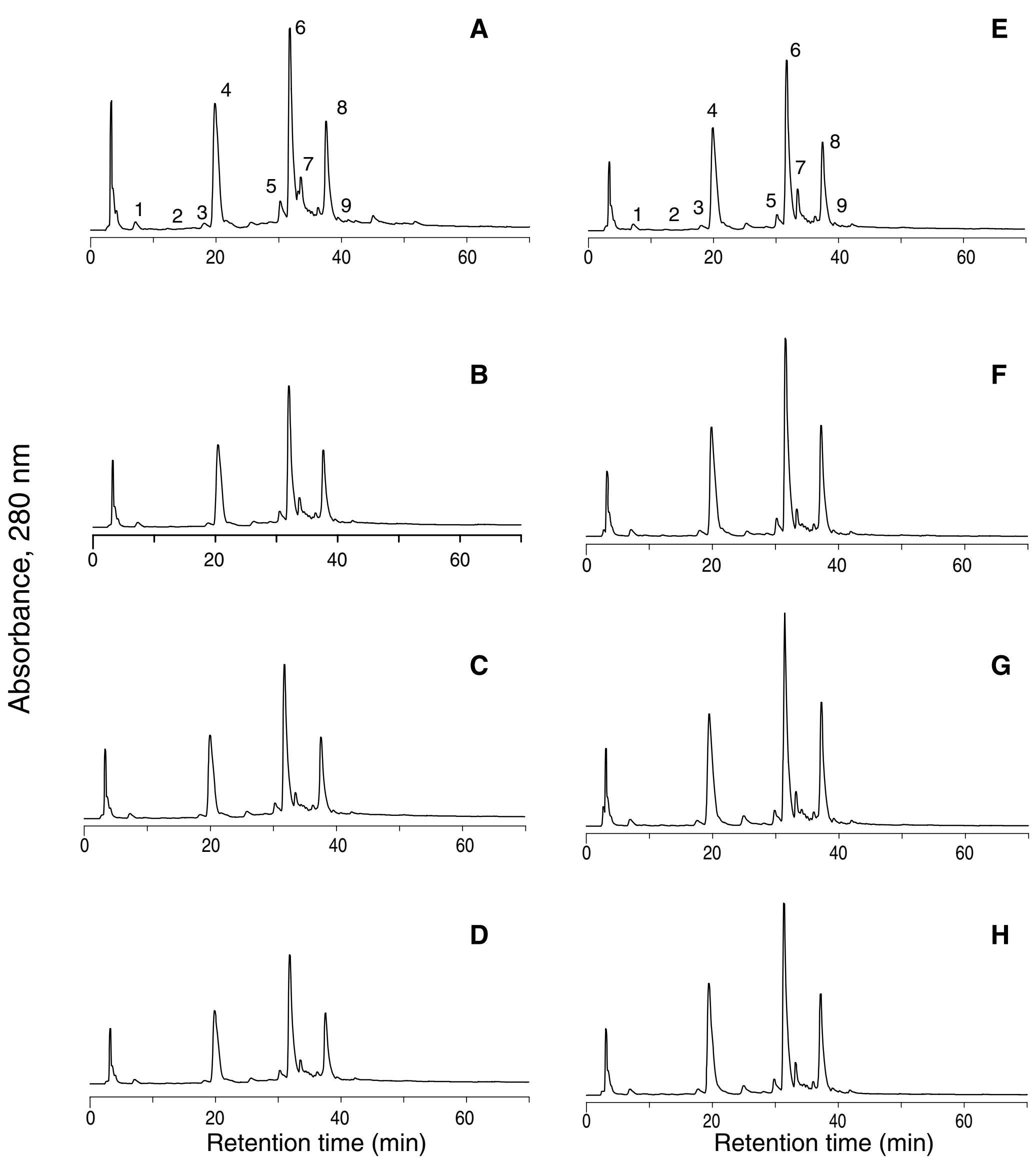

Figure 3 – HPLC chromatograms of extracts from tea leaves during processing of Korean Kamairi-cha. (A): Raw leaves; (B): 1st roasting; (C): 1st rolling; (D): 2nd roasting; (E): 2nd rolling; (F): 1st firing; (G): 2nd firing; (H): tea. Peaks: (1) theobromine; (2) theophylline; (3) epigallocatechin; (4) caffeine; (5) catechin; (6) epicatechin; (7) epigallocatechin gallate; (8) gallocatechin gallate; (9) epicatechin gallate; (10) catechin gallate. Theaflavins (not present in these extracts) elute between 55 and 65 min.

Table 3 – Changes in alkaloid (theobromine, theophylline, and caffeine) and catechin (epigallocatechin [EGC], catechin [C], epicatechin [EC], epigallocatechin gallate [EGCG], gallocatechin gallate [GCG], epicatechin gallate [ECG], and catechin gallate [CG]) contents in tea leaves during the preparation of Korean Kamairi-cha green tea.[A]

Processing conditions[a]	Theobromine	Theophylline	Caffeine	Total alkaloids	EGC	EC	C	EGCG	GCG	ECG	CG	Total catechins
Raw leaves	1.22 ± 0.09	0.22 ± 0.05	25.13 ± 0.48	26.57 ± 0.49	9.53 ± 0.78	8.91 ± 0.45	5.55 ± 0.86	49.29 ± 1.44	6.43 ± 0.29	26.98 ± 2.68	1.26 ± 0.29	107.95 ± 3.31
1st roasting	1.15 ± 0.14	0.11 ± 0.01	26.04 ± 2.58	27.30 ± 2.58	9.21 ± 0.83	7.43 ± 0.33	6.15 ± 0.54	52.73 ± 3.82	4.27 ± 0.82[b,d]	29.55 ± 2.06	0.98 ± 0.22	110.32 ± 4.54
1st rolling	1.17 ± 0.11	0.11 ± 0.02	24.44 ± 1.23	25.72 ± 1.24	7.97 ± 1.21	8.32 ± 0.39	7.35 ± 0.62[e]	45.36 ± 2.15[b]	4.22 ± 0.06[d]	29.56 ± 2.62	0.95 ± 0.18	103.73 ± 3.67
2nd roasting	1.10 ± 0.14	0.11 ± 0.02	24.27 ± 1.03	25.48 ± 1.31	5.91 ± 1.43[d]	7.62 ± 0.32	6.13 ± 0.37	47.70 ± 1.22	3.84 ± 0.38[d]	29.27 ± 0.96	1.11 ± 0.18	101.58 ± 2.21
2nd rolling	1.24 ± 0.04	0.11 ± 0.01	24.63 ± 0.33	25.98 ± 0.34	1.01 ± 0.04[b,d]	7.44 ± 0.33	6.44 ± 0.09	46.67 ± 2.00	4.87 ± 0.50[d]	28.06 ± 0.77	1.05 ± 0.21	95.54 ± 2.23
1st firing	1.35 ± 0.06	1.04 ± 0.06[b,d]	22.82 ± 1.42	25.21 ± 1.42	1.33 ± 0.11[d]	7.38 ± 1.11	7.19 ± 0.46	46.10 ± 3.11	3.02 ± 0.13[b,d]	29.60 ± 1.86	1.29 ± 0.07	95.91 ± 3.83
2nd firing	1.52 ± 0.05[d]	0.91 ± 0.02[d]	25.59 ± 0.24	28.02 ± 0.25	1.20 ± 0.01[d]	7.45 ± 0.18	9.48 ± 0.66[b,d]	47.58 ± 0.63	3.71 ± 0.11[d]	31.41 ± 0.76	1.42 ± 0.16	102.25 ± 1.22
Green tea	1.37 ± 0.06	1.06 ± 0.09[c,d]	24.44 ± 0.75	26.87 ± 0.76	1.22 ± 0.08[d]	6.93 ± 0.72[d]	9.89 ± 0.56[d]	42.95 ± 2.38	3.61 ± 0.20[d]	26.43 ± 1.22	1.50 ± 0.15	92.53 ± 2.84[d]

[A]Listed values are expressed as average (mg/g dry weight) ± SD; $n = 3$. Shading indicates significantly different than previous step.
[a]See Table 1.
[b]Significantly different than the previous processing step ($P < 0.001$).
[c]Significantly different than the previous processing step ($P = 0.002$).
[d]Significantly different than the starting material (raw leaves) ($P < 0.001$).
[e]Significantly different than the starting material (raw leaves) ($P = 0.002$).

product. The theanine content (in milligrams per gram dry wt) of Kamairi-cha green tea of 21.67 ± 0.42 ($n = 3$) was much higher than the range of 6.1 to 11.4 we previously reported for 8 commercial green teas sold in the United States (Friedman and others 2005).

Conclusions

The results obtained in this study indicate that pan-frying of tea leaves harvested in Korea induces nearly quantitative reductions in moisture and chlorophyll content of the final green Kamairi-cha tea product. Processing of the raw leaves to produce Kamairi-cha tea induced a 14% loss in total catechin content. There were no overall losses in alkaloid content. The concentration of the minor catechin (catechin) increased by 78%. Three other minor catechins, epigallocatechin, gallocatechin gallate, and epicatechin, decreased by 87%, 44%, and 22%, respectively. There were no significant changes in the most abundant catechins epigallocatechin gallate and epicatechin gallate. The final product contained no theaflavins (normally found in black and occasionally in green teas) and a high amount of theanine.

It is also interesting to note as to which processing stages induced changes in composition. Moisture content changed significantly at the 1st roasting and at the firing stages. These are also the stages at which we found the largest losses of gallocatechin gallate. Gallocatechin gallate may be most susceptible to moisture levels or to heat applied. Much of the epigallocatechin present was lost during the 2nd rolling. In addition, there was a smaller loss of epigallocatechin gallate during the 1st rolling. Rolling is sometimes referred to as bruising, as it releases some of the leaf juices that may induce oxidation reactions. It appears that epigallocatechin may be highly susceptible to chemical oxidation. Catechin increased significantly during the 2nd firing. We noticed that the content of this catechin was more variable through the processing steps; values increased, decreased, then increased again, possibly as a result of poor extractability. Alternatively, epimerization could also be responsible for some of this variability, as well as for some of the variations in losses seen in the other catechins. For example, epicatechin could have epimerized to catechin, which in turn could have partially degraded. With the 2 processes of epimerization and degradation working together, the losses of individual catechins are difficult to predict.

Overall, with a catechin loss of only 14%, the health-promoting potential Kamairi-cha tea appears promising. The total catechin content of this pan-fried green tea of approximately 92.5 mg/g approaches the highest amount of 100 mg/g previously determined among 24 commercial green teas sold in the United States (Friedman and others 2005, 2006b). This high-quality tea with unique flavor attributes has the potential to be an important addition to commercial teas and tea products.

The described observations will hopefully stimulate needed studies on maximizing the levels of beneficial tea ingredients during each of the multiple processing steps to which harvested tea leaves are exposed during production of commercial green teas and tea products.

Finally, whether exposure of tea leaves during pan-frying to up to approximately 300 °C will degrade potentially toxic acrylamide that may be formed in teas roasted at lower temperatures (Mizukami and others 2006; Friedman and Levin 2008) merits further study.

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